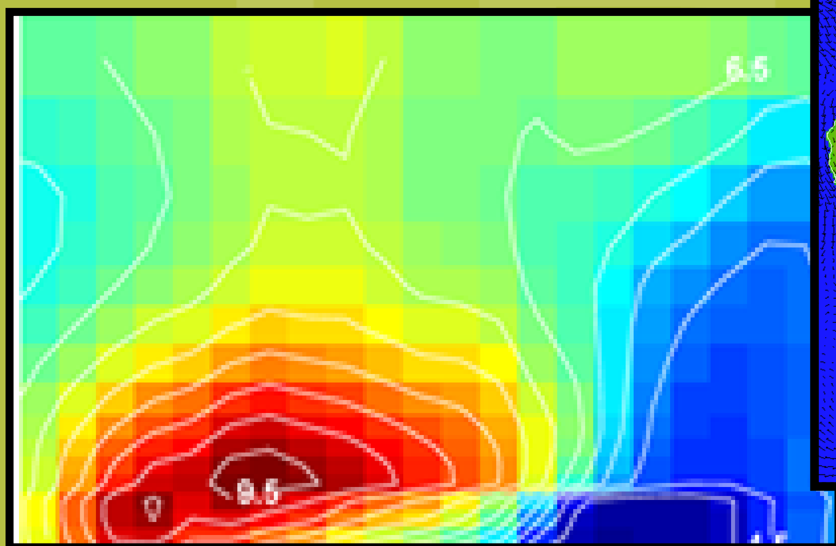
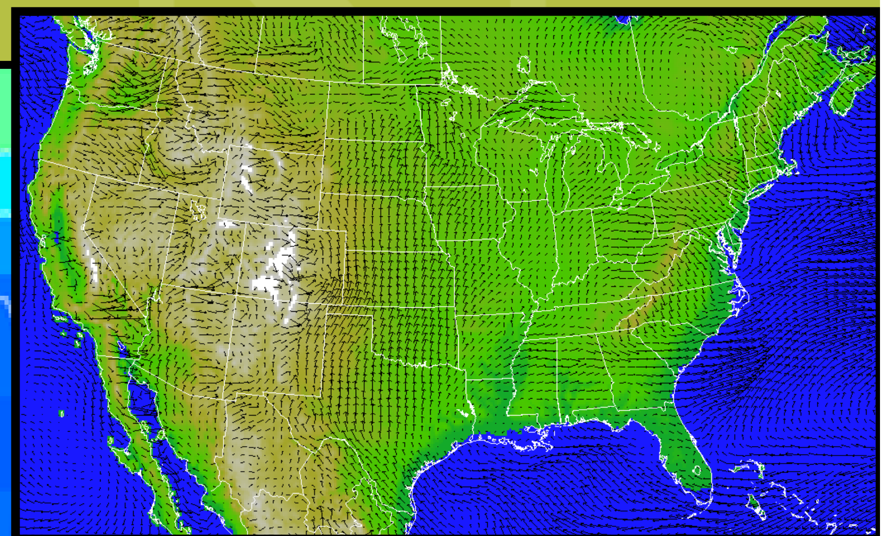
Pleim-Xiu LSM, ACM2 PBL in WRF-ARW for Retrospective Air Quality Applications: Past, Present and Future

Rob Gilliam, US EPA

Ad Hoc Meteorological Modelers Meeting

June 26, 2009





Office of Research and Development
National Exposure Research Lab, Atmospheric Modeling and Analysis Division, Atmospheric Model Development Branch

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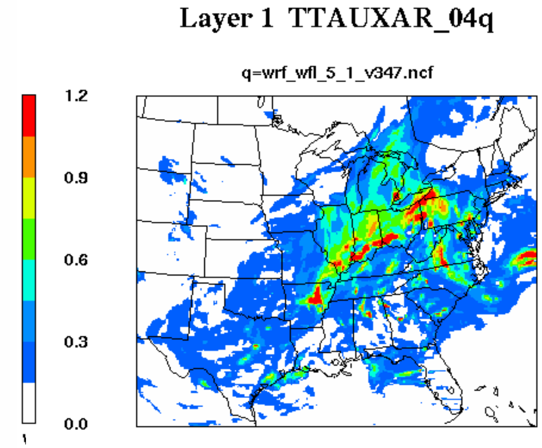
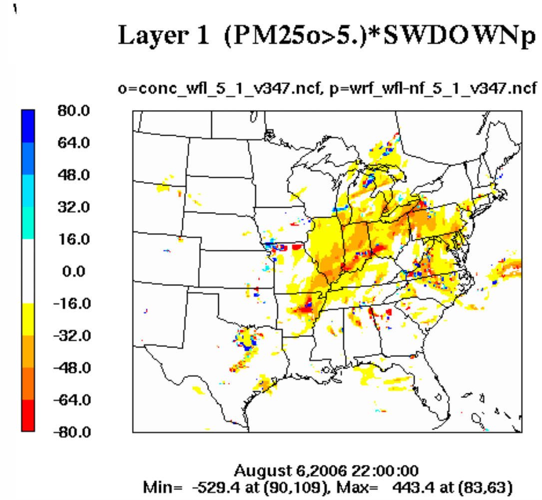
US EPA's transition from MM5 to WRF

- MM4 and MM5 have been the main mesoscale model used for CMAQ air quality simulations for 20+ years
- WRF-ARW is the model that has been chosen to replace MM5 (MM5 development ceased in 2004)
- Our requirements include:
  - Compatibility with CMAQ (Otte in 2005)
  - Pleim-Xiu LSM, ACM2 PBL, Pleim surface layer (2007)
  - Pleim-Xiu updates (2007-2009)
  - Four Dimensional Data Assimilation (FDDA) (NCAR/PSU in 2007)
  - RAWIN-LittleR like tool for WRF-ARW ***Obsgrid*** (NCAR/PSU in 2008)
  - Performance on par (or better) than MM5 (2009); CMAQ performance as well.

Compatibility (WRF-AWR) w/ CMAQ

- Tanya Otte modified MCIP to translate WRF output for CMAQ
- Ongoing updates and changes have been made since the first version in 2005
- US EPA (David Wong) has developed an online, two-way WRF-CMAQ modeling system
  - Meteorology passed to CMAQ at user defined interval (each WRF timestep for every 4-5 WRF timesteps)
  - Direct feedback of aerosols on radiation considered (AOD passed from CMAQ to WRF's CAM radiation scheme)





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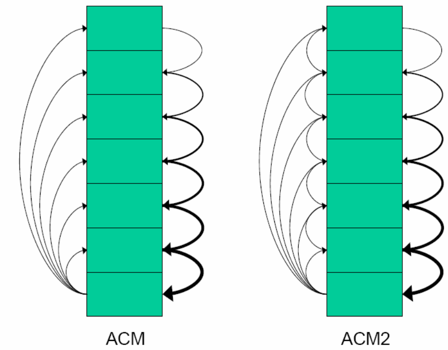
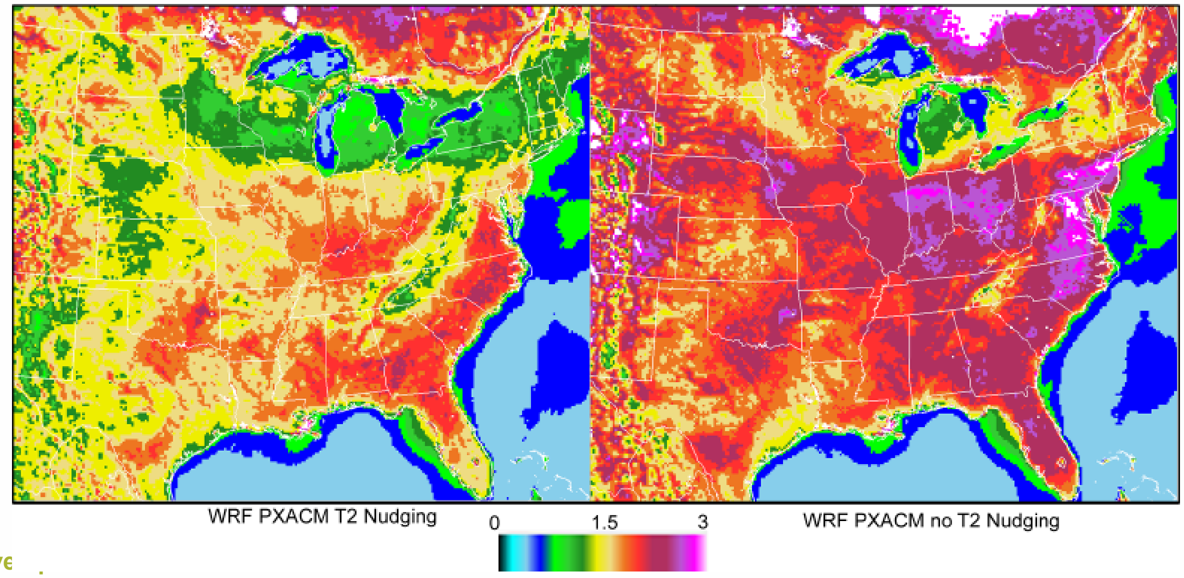
Implementation of new physics in WRF-ARW



- Pleim-Xiu LSM, Asymmetric Convective Model (ACM2) and Pleim surface layer scheme from MM5 was ported to WRF in 2007
- ACM2 PBL model (Pleim, 2007)
  - non-local scheme for convective PBL w/ some stability related local upward transport
  - Eddy diffusion for stable PBL
- Pleim similarity scheme or the surface layer (Pleim, 2006)
- Pleim-Xiu LSM (Xiu and Pleim, 2001, Pleim and Xiu, 2003)
  - Indirect soil nudging
  - Weighted Veg Frac, LAI, Zo and Albedo according to LU fraction
  - snow specified by 3-hr analysis

Updates to Pleim-Xiu LSM

- Deep soil temperature nudging to improve cold season simulations and the predictions over surfaces that have low vegetation
- Landuse-based snow fraction and surface heat capacity (i.e., 100% snow cover requires more snow over a forest as compared to a grass covered field)
- Albedo now weighted according to landuse fractions rather than dominate landuse
- National Land Cover Data (NLCD) version of PX LSM is being tested and will be released soon.



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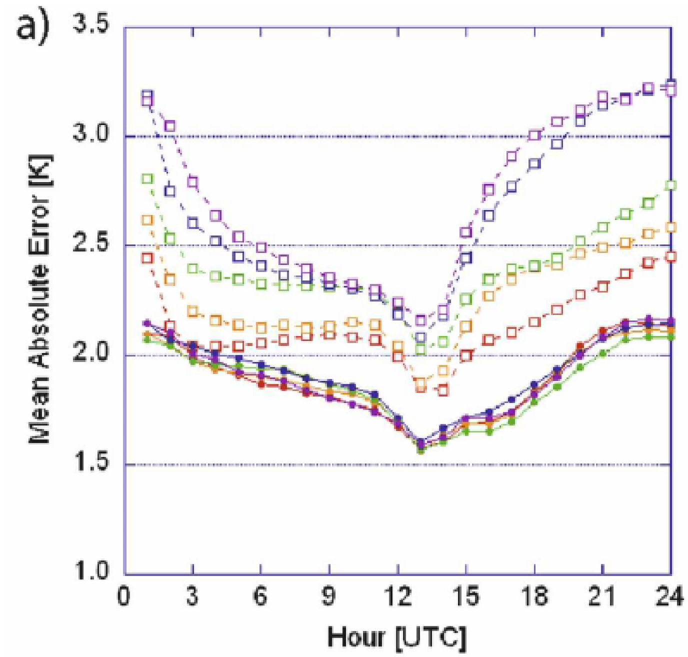
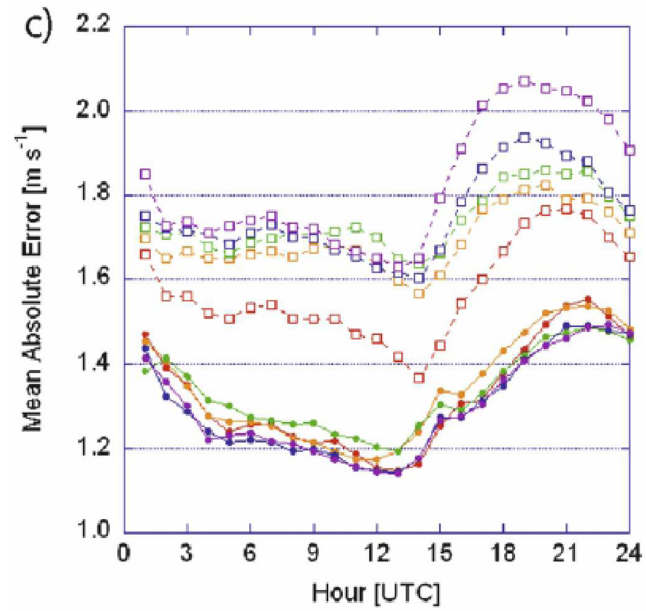
Four Dimensional Data Assimilation (FDDA)

- Analysis nudging is a main tool for retrospective modeling
- EPA contract w/ PSU and NCAR led to implementation of FDDA in WRF Version 2.2 (Dec 2006)





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Obsgrid objective re-analysis utility

- Equivalent to MM5's RAWINS and LITTLE_r; initial version for testing was available July 2008, new version release with WRFV3.1 that included the compatibility with the new surface layer nudging
- Fuses a base analysis (WPS met_em* files) and observations (Cressman OA)
  - 3-D re-analyses for FDDA
  - 2-D surface re-analysis for surface nudging
  - 2-D T2, Q2 for PX LSM indirect soil nudging
- Observation QC and buddy checks, Radius of Influence
- Allows the use of any Little_r observation file, so we are testing use of non-standard ACARS, wind profiler, satellite wind and mesonet surface observations. Results of these experiments are not provided here because surface nudging masks the impact; we are retesting without surface nudging.

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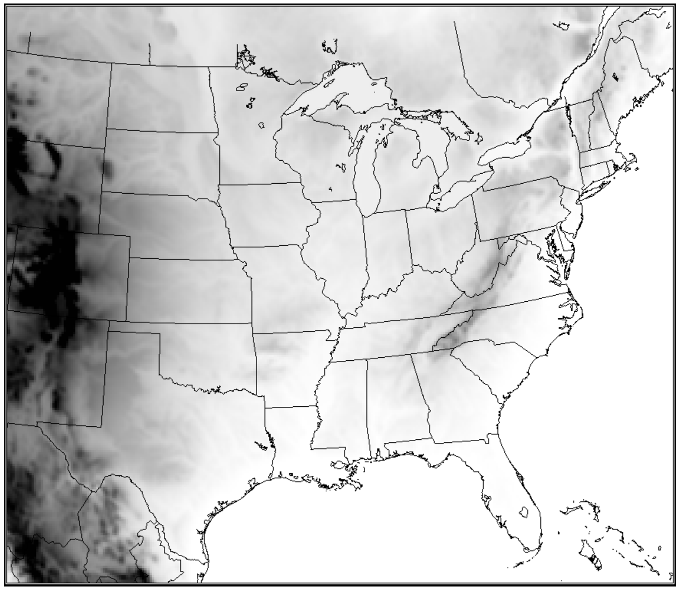
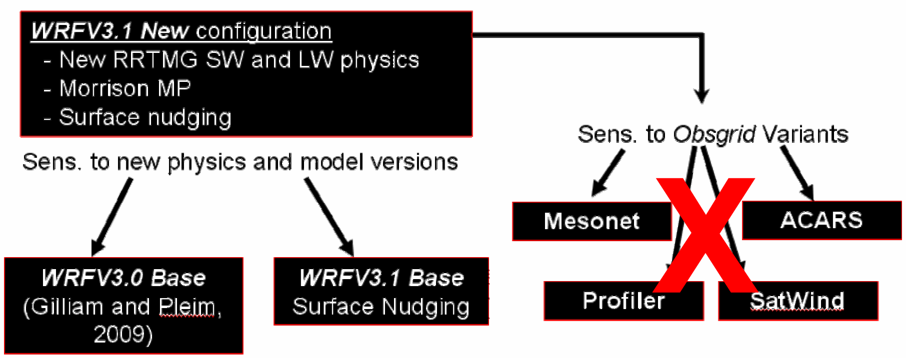
Experimental Simulations





Common Simulation Characteristics

- WRF-ARW Version 3.1
- 12 km Eastern US domain with 34 levels
- Simulation period: Jan 1-6 and Jul 31- Aug 4, 2006
- WPS used NCEP NAM 12 km 6 hourly analyses and 3 hr forecasts
- *Obsgrid* use standard surface and twice-daily upper-air balloon soundings
- FDDA (grid nudging) done for temperature, moisture above PBL and wind at all levels
- Simulations were 5.5 days; first 12 hours discarded as a spin-up period

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Domain-wide RMSE for key near surface variables

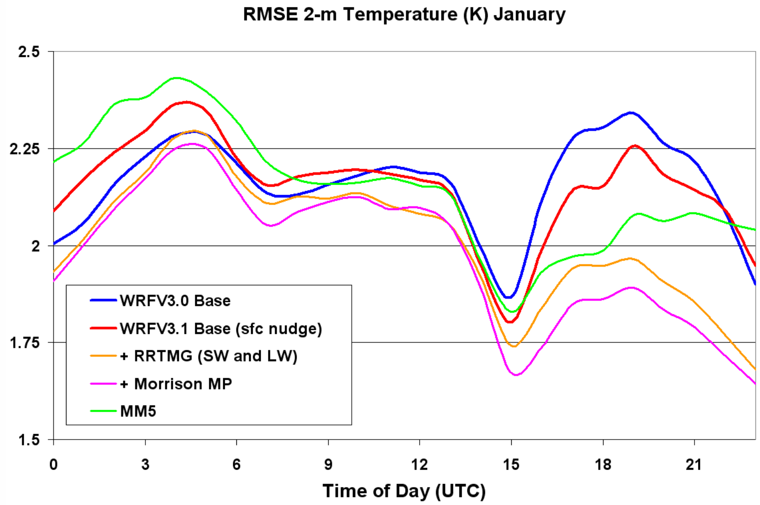
RMSE	MM5	WRFV3.0 Base	WRFV3.1 Sfcnudge	RRTM_AER	WRFV3.1 New plus Morrison MP
2-m Temperature (K) January	2.17	2.18	2.10	2.02	1.99
2-m Mixing Ratio ($g\ kg^{-1}$) January	0.81	0.89	0.85	0.85	0.85
10-m Wind Speed ($m\ s^{-1}$) January	1.57	1.58	1.54	1.53	1.53
10-m Wind Dir (deg) January	25	22	23	23	23

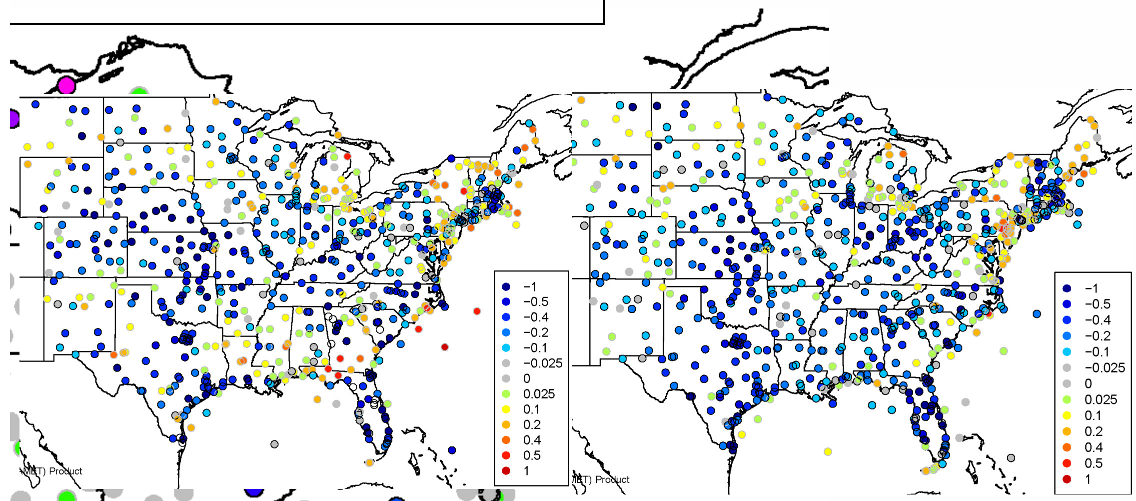
RMSE	MM5	WRFV3.0 Base	WRFV3.1 Sfcnudge	RRTM_AER	plus Morrison MP
2-m Temperature (K) August	2.03	2.01	2.00	2.02	1.99
2-m Mixing Ratio ($g\ kg^{-1}$) August	2.08	2.04	2.09	2.16	2.13
10-m Wind Speed ($m\ s^{-1}$) August	1.56	1.52	1.52	1.51	1.50
10-m Wind Dir (deg) August	30	28	31	29	29

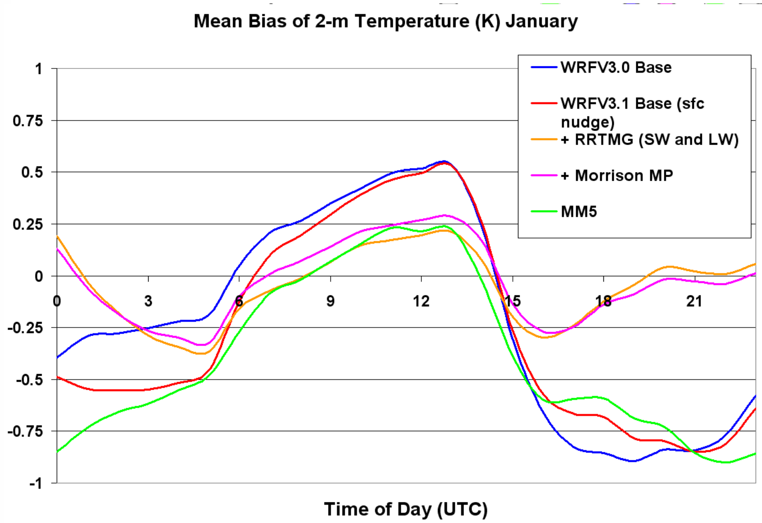
Lowest RMSE Highest RMSE

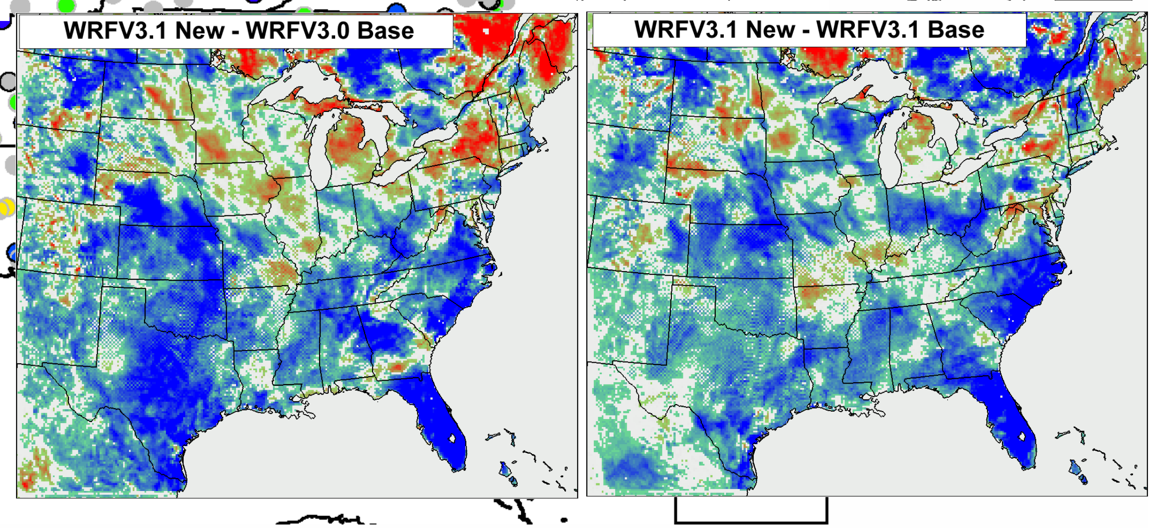
2-m Temperature (January)

WRFV3.1 New – MM5









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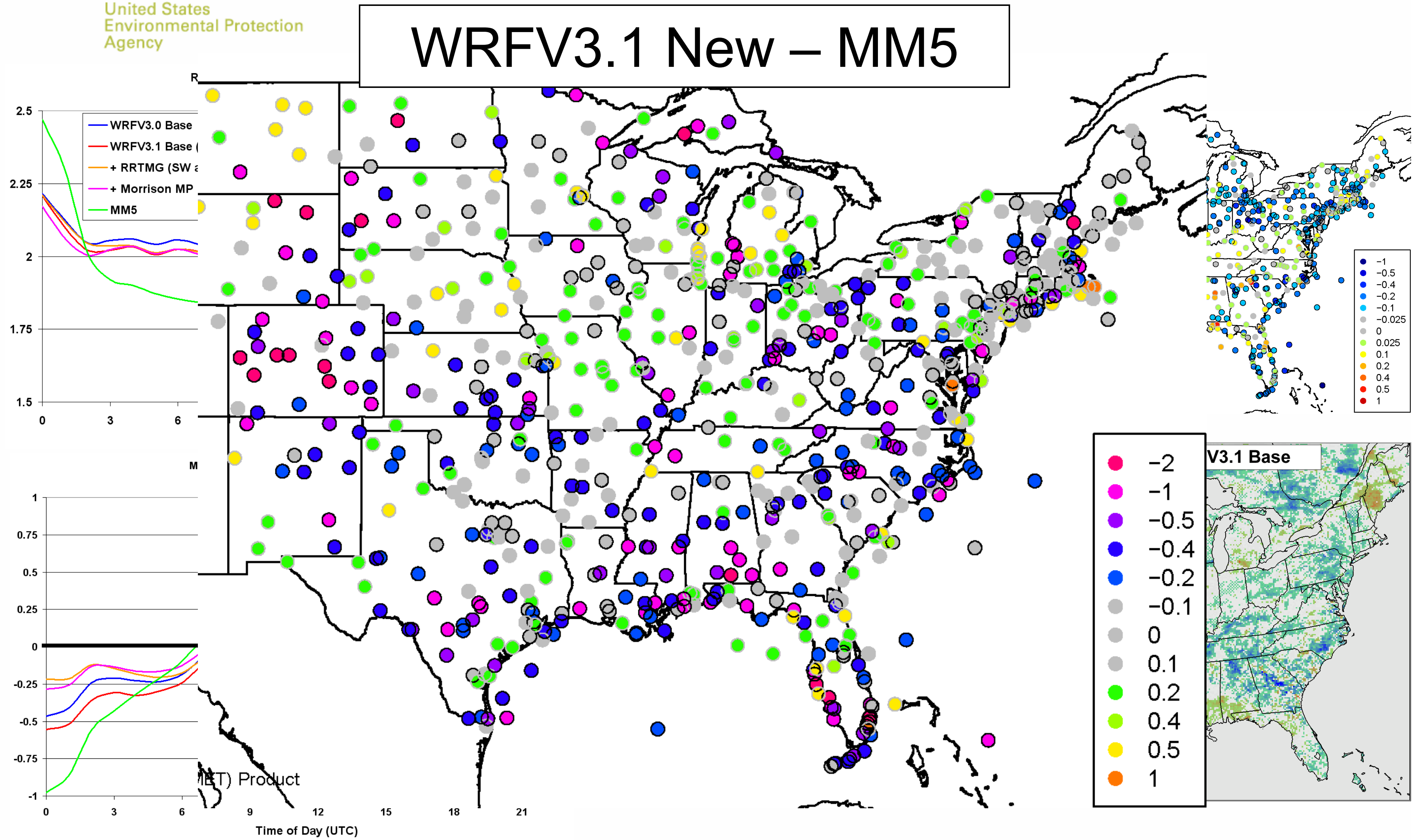
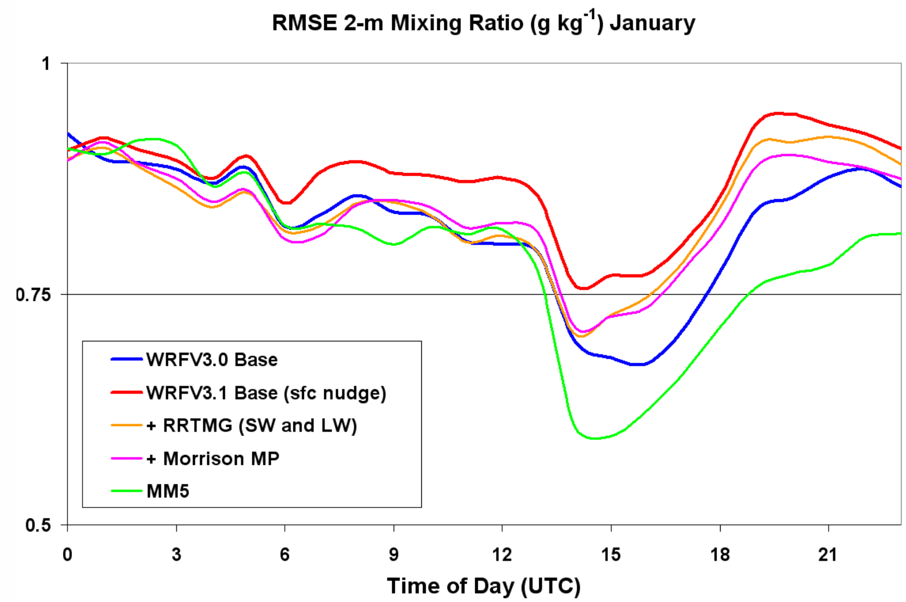
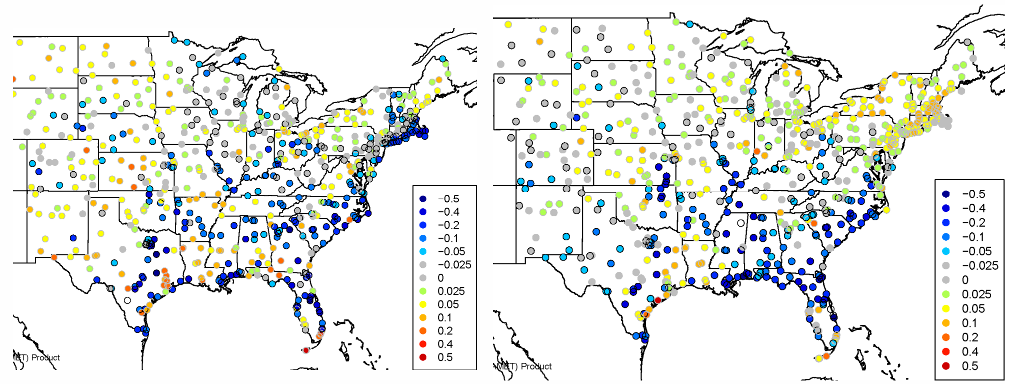
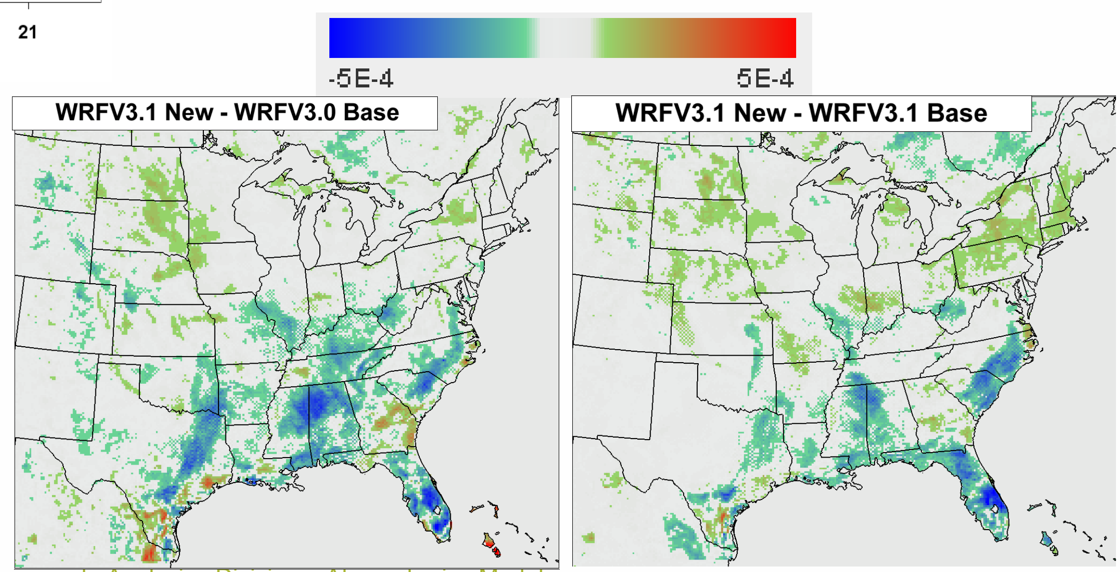
2-m Temperature (August)



2-m Mixing Ratio (January)







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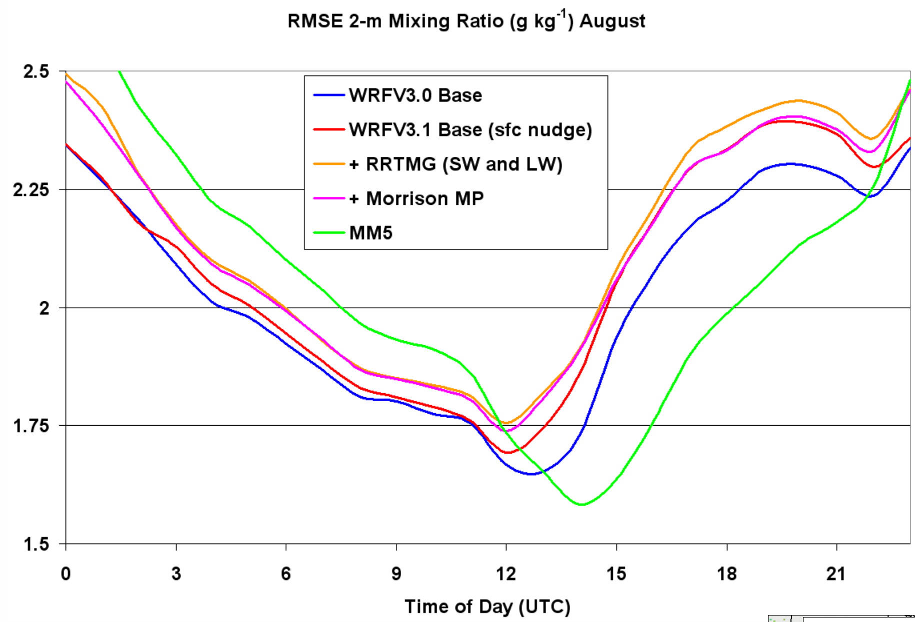

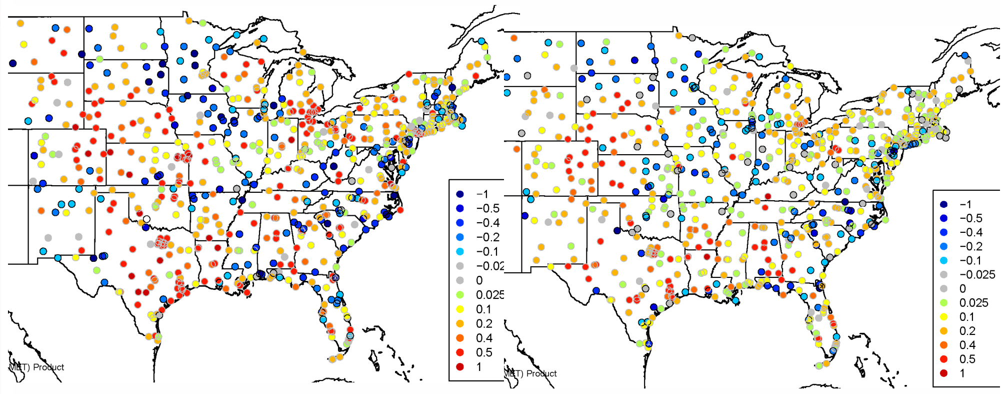

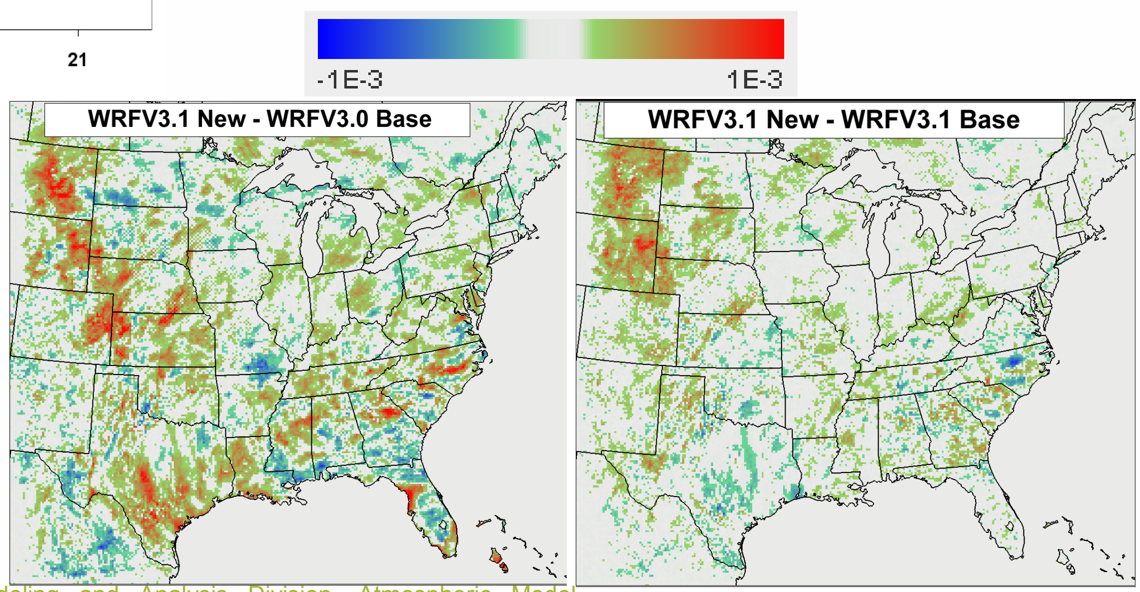

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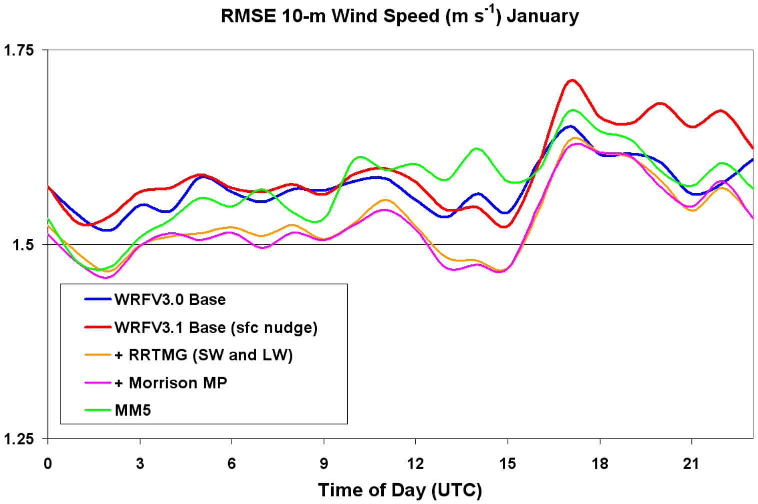
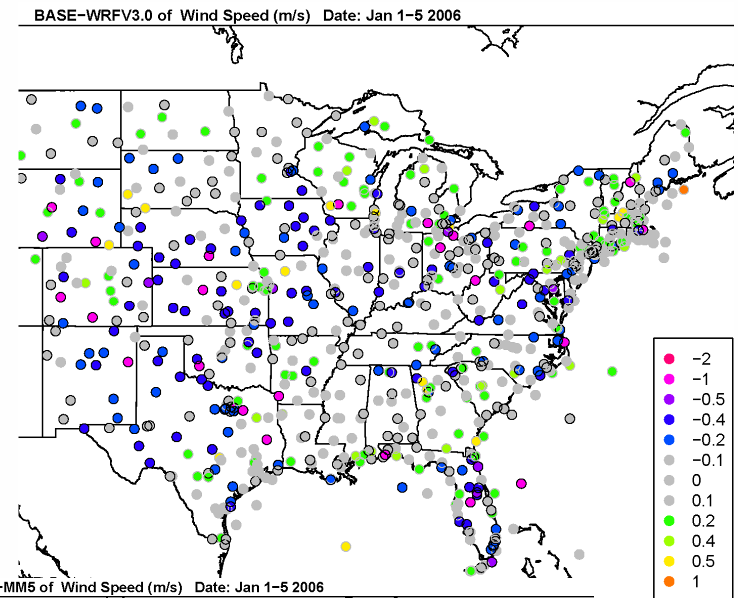
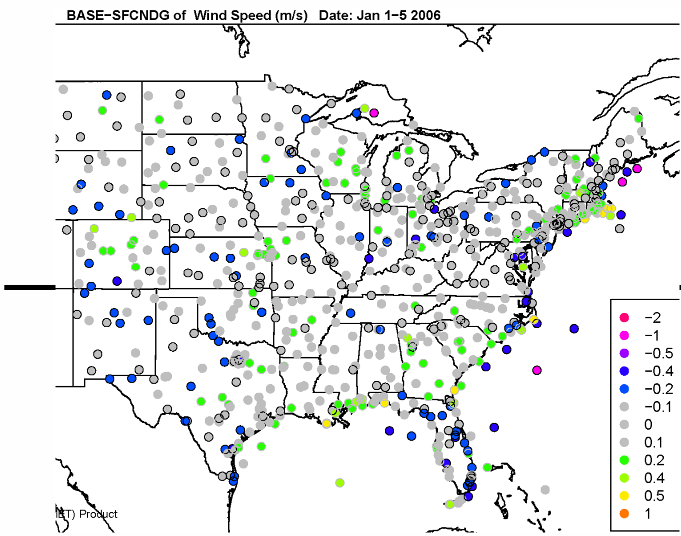
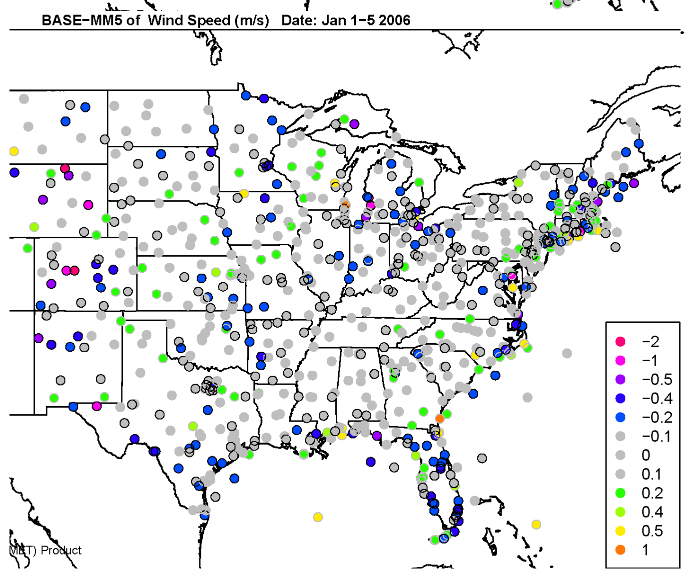
10-m Wind Speed (January)









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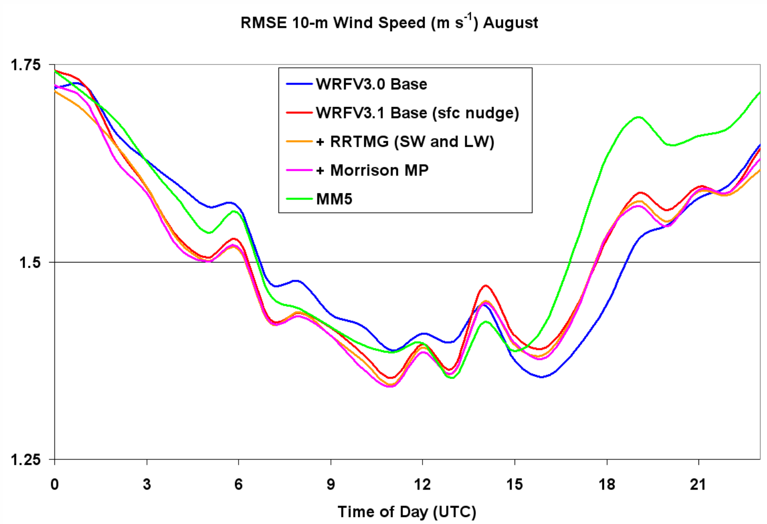
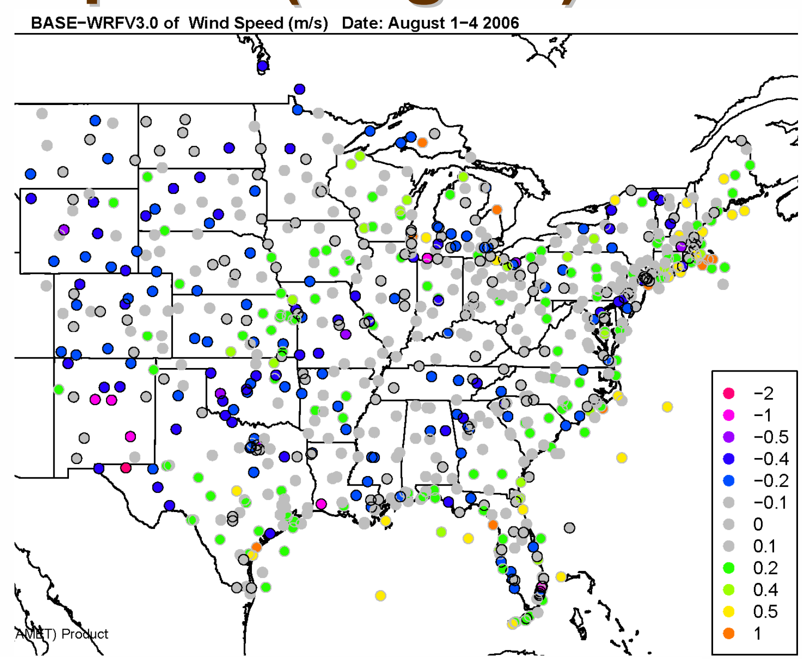
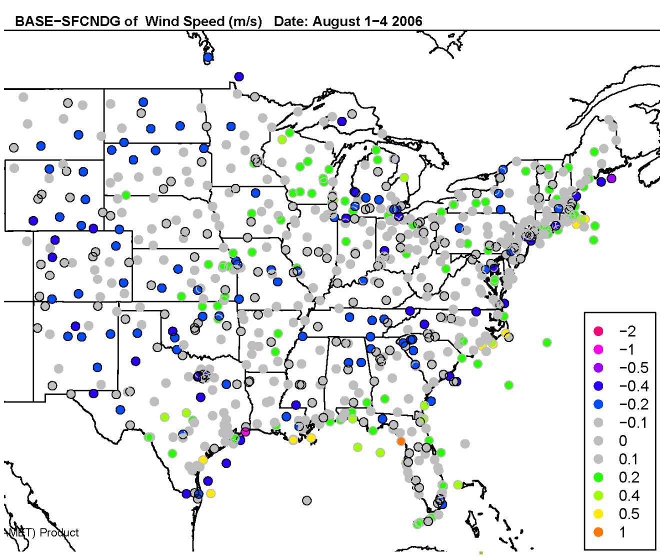
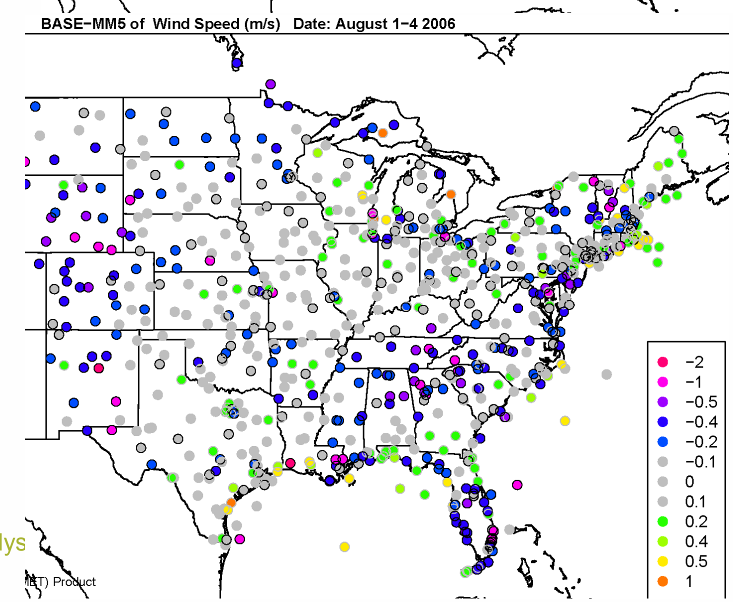
10-m Wind Speed (August)









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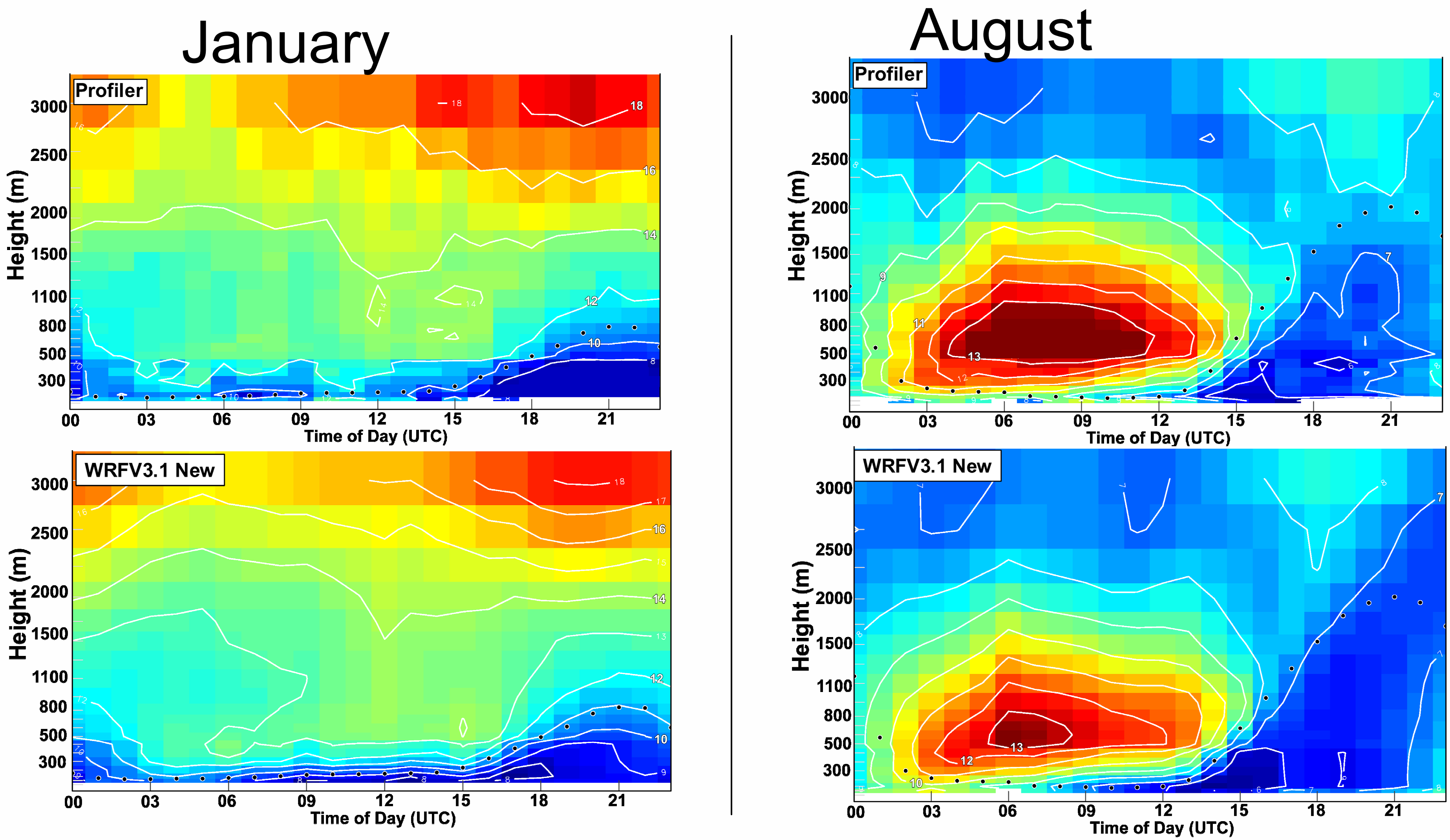
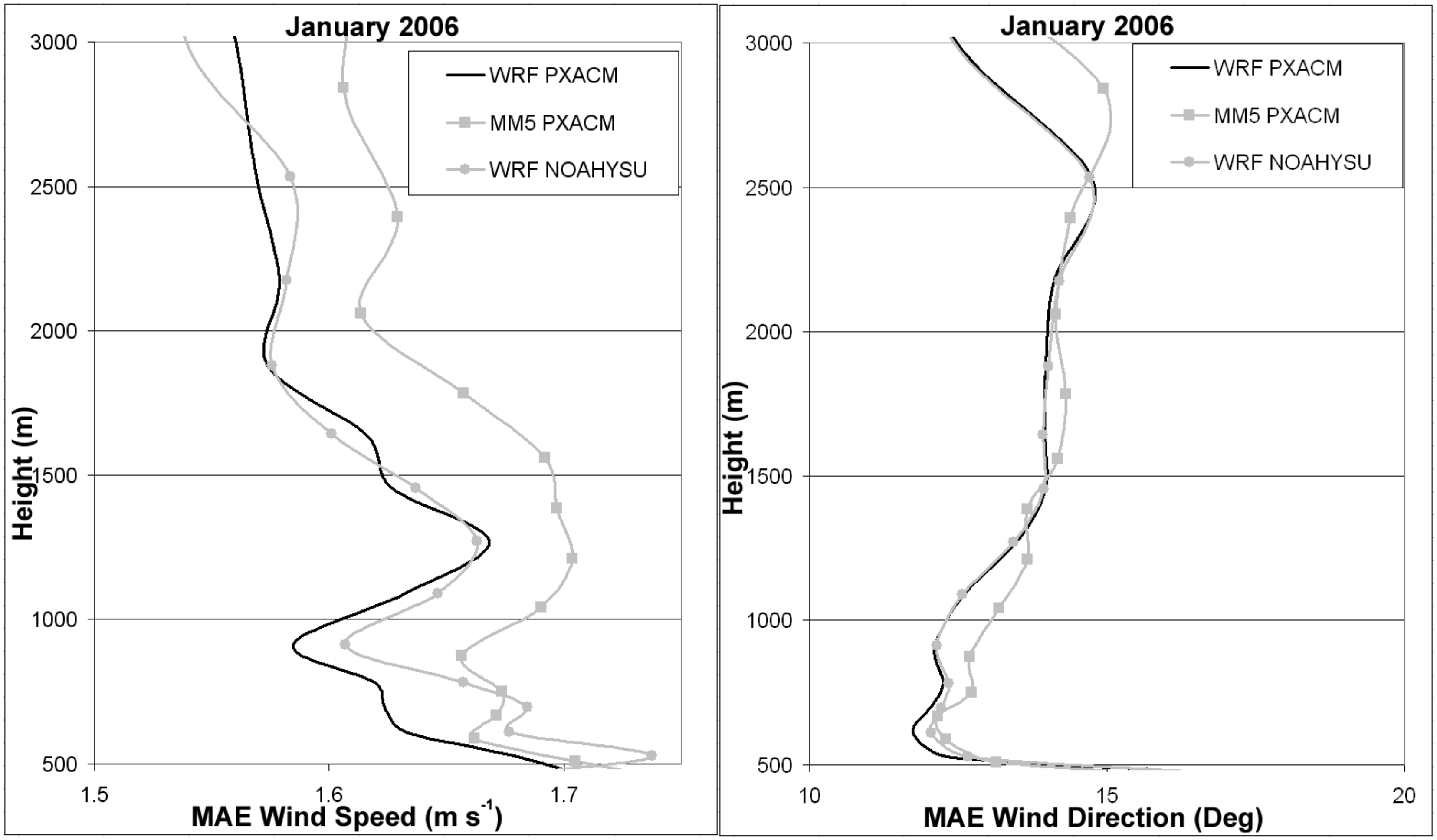
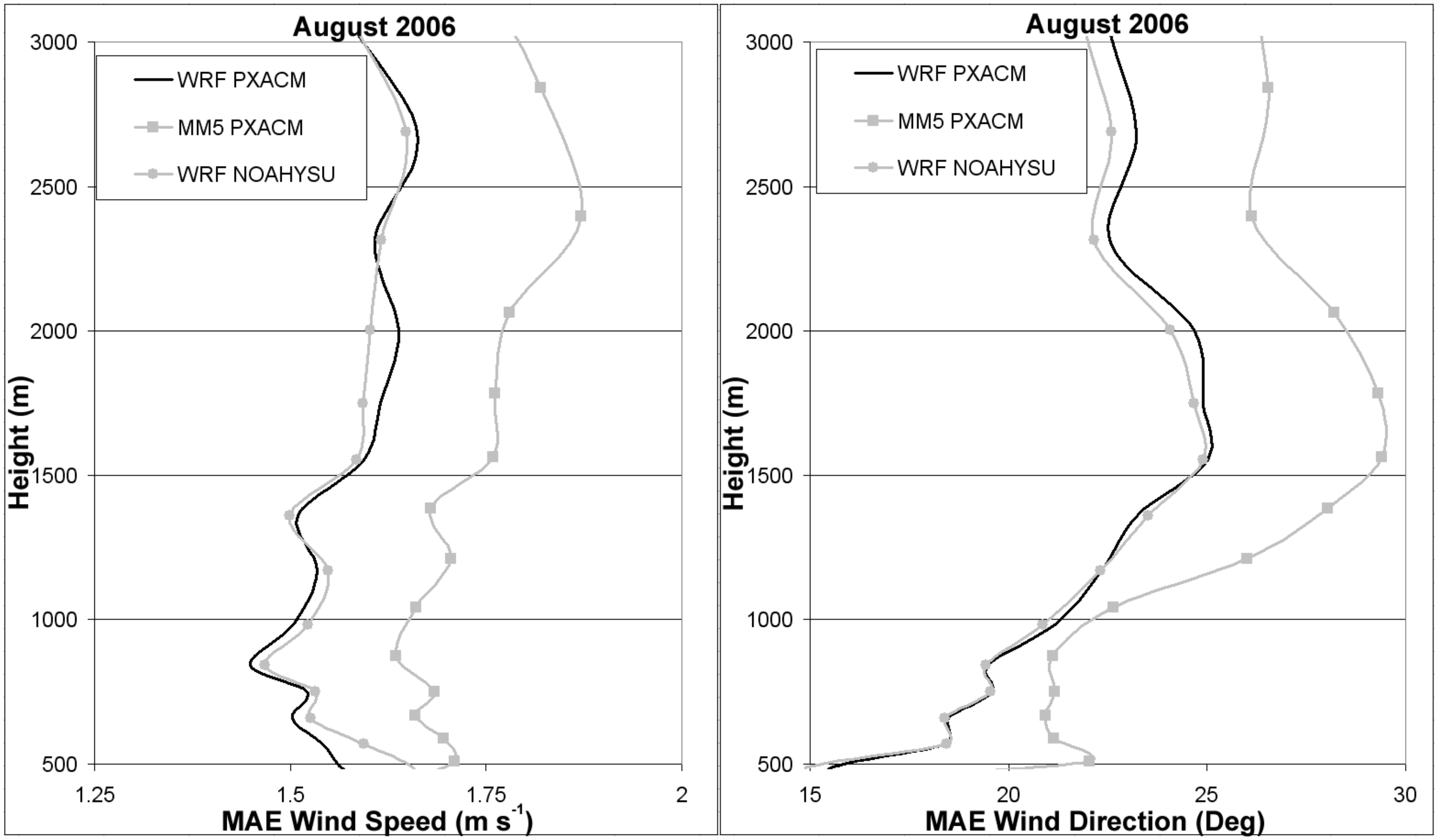
PBL Wind Speed



Simulated PBL Wind (Jan 2006)



Simulated PBL Wind (Aug 2006)



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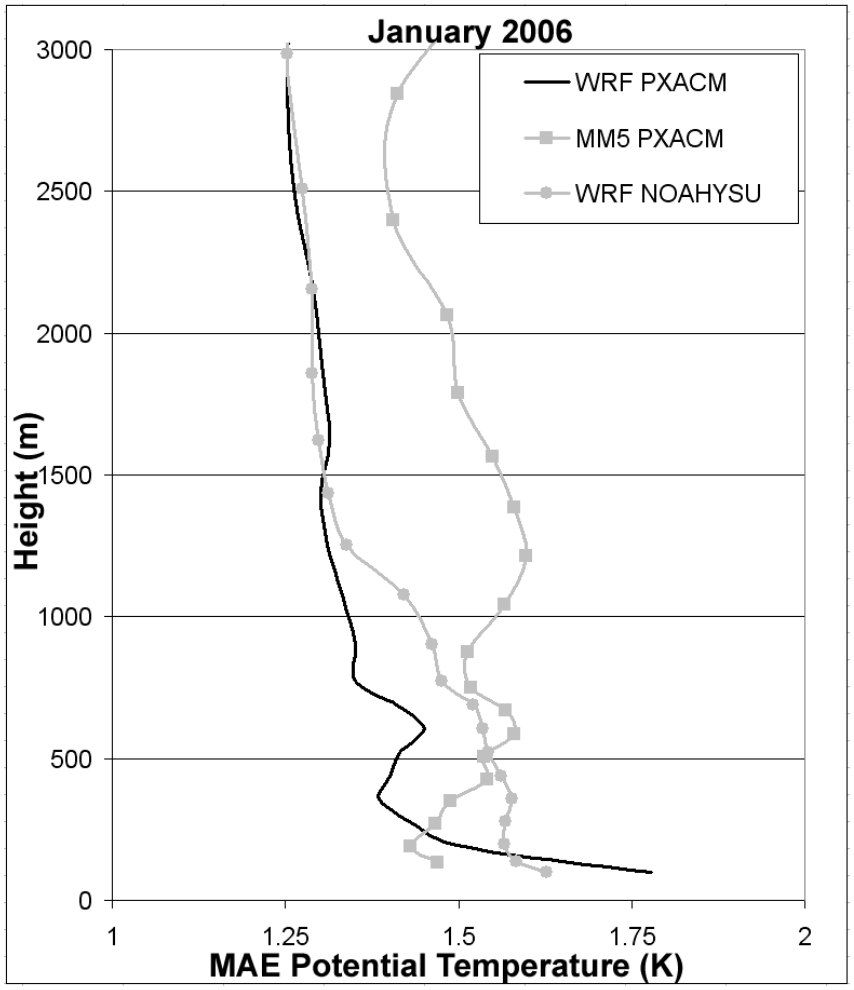
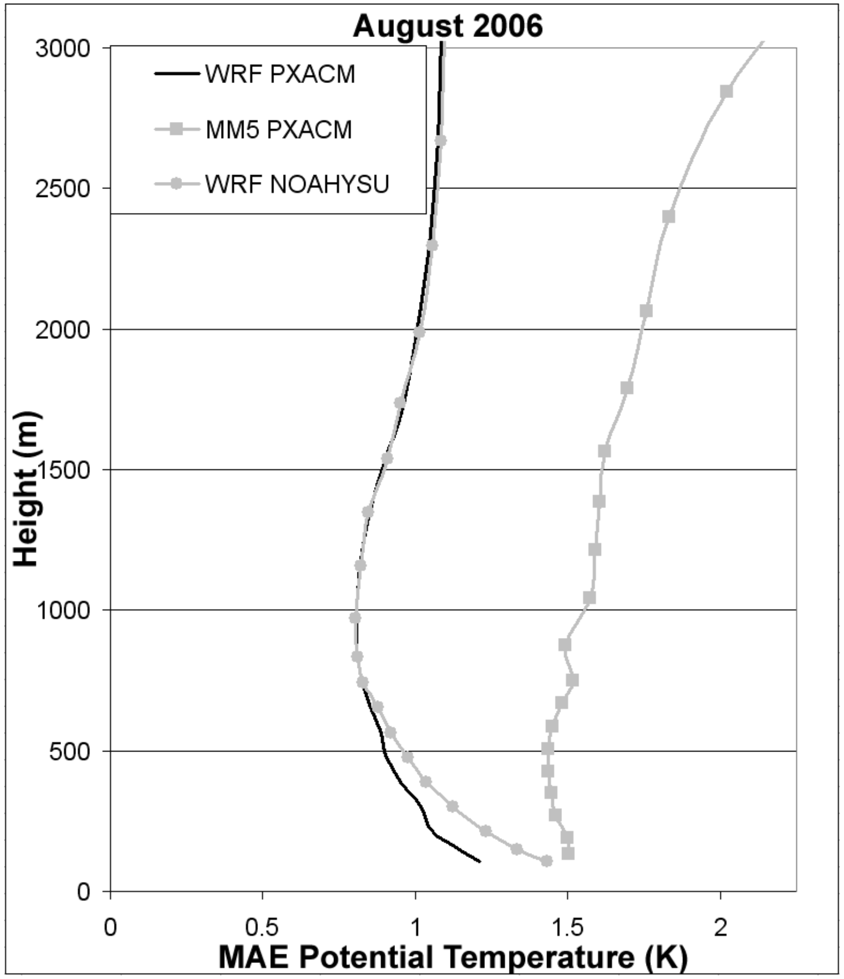
Simulated PBL Potential Temperature





Conclusion

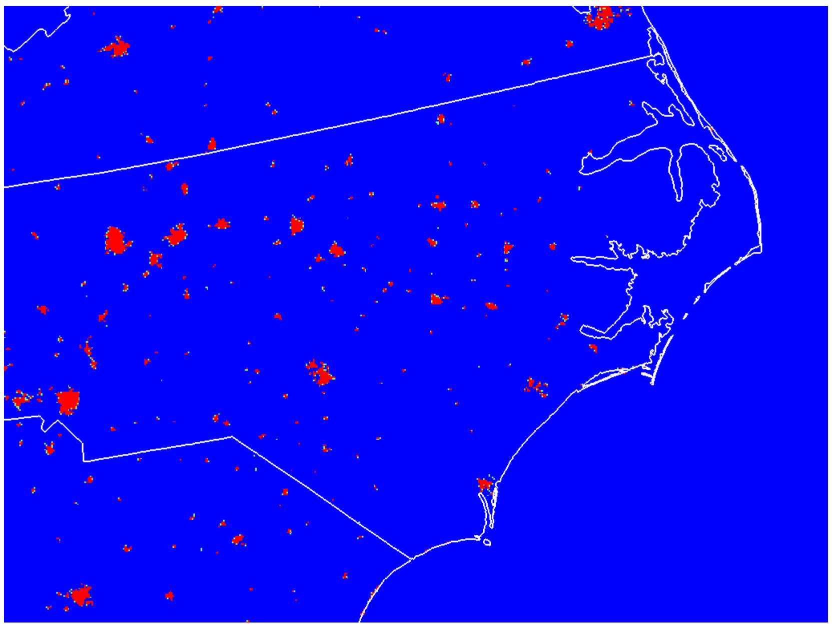
- WRF Version 3.1 simulations with P-X LSM and ACM2 PBL and the new radiation and microphysics have some of the lowest errors of any retrospective simulations the US EPA has used.
- 2-m Mixing ratio error is slightly greater overall during the warm season.
- PBL wind and temperature are simulated with very low uncertainty with errors lower than the near surface estimates; potential temperature errors were around 1 K in the PBL during August.
- Wind profiler and aircraft observations are valuable to assess the model performance in the PBL; may prove to be important for FDDA
- WRF performance using the Pleim-Xiu LSM and ACM2 PBL is at or above the level of MM5 for retrospective meteorological simulations; we should officially transition to WRF if these results hold across longer simulations periods and CMAQ results are inline with the improvements in meteorology.

Future efforts

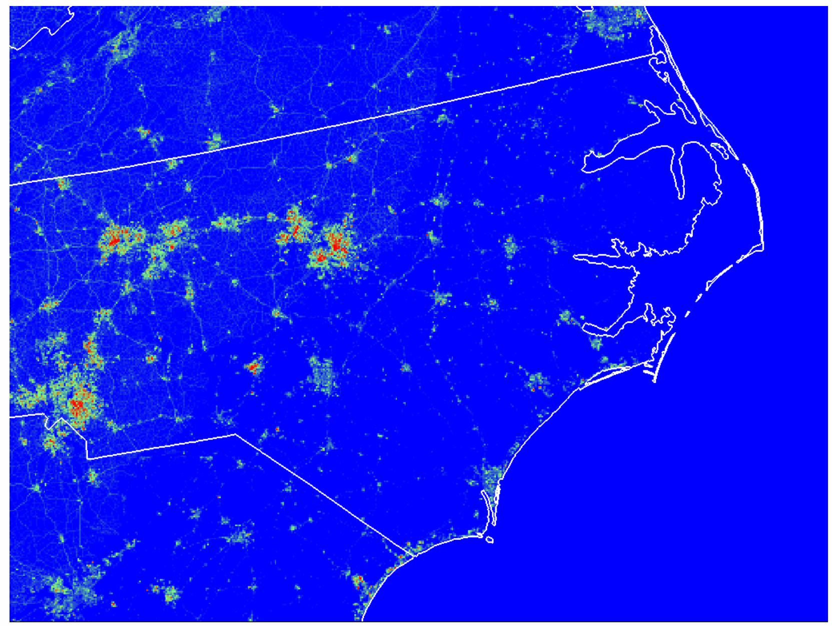
- Further improving Obsgrid analyses by providing wind profiler, satellite wind, aircraft and other non-standard observations
- 2-way coupled WRF-CMAQ under development
  - Includes direct radiative feedback of aerosol to SW radiation simulated by the CAM radiation model
- Advanced data assimilation including 3d-var, obs nudging and hybrid schemes

Future efforts

- National Land Cover Data for more accurate landuse



USGS Fraction of Urban



NLCD Fraction of Urban